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MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 462

MEASUREMENT OF THE DYNAMIC UNDERCARRIAGE RESPONSE OF A SIKORSKY S-70B-2 HELICOPTER -INSTRUMENTATION AND TEST METHODS

by

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SUMMARY

The instrumentation and techniques are described which were used to measure the dynamic undercarriage response of a Royal Australian Navy S-70B-2 Seahawk helicopter.

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CONTENTS

1. INTRODUCTION

A series of ground tests has been undertaken to determine the dynamic response characteristics of the undercarriage (tyres and oleos) of a Sikorsky S-70B-2 Seahawk helicopter. The tests provided data for the validation of the undercarriage component of the Aeronautical Research Laboratory (ARL) helicopter/ship interface model (Reference 1).

An aircraft with fuselage marking 70, Serial N24-001 had its main and tail rotor blades, and its horizontal stabilizers removed before the tests. Displacement measuring transducers were fitted to its landing gear oleo struts and tyres and a motion platform installed in the fuselage to provide the fuselage motion data occurring during the tests. The data were recorded using the ARL Versatile Airborne Data Acquisition and Replay (VADAR) data acquisition system.

A mobile crane was used to lift the aircraft fuselage to allow one landing gear leg to be extended a predetermined amount. Operating an electrical quick-release hook allowed the aircraft to fall from its raised position to apply a step input to the landing gear leg to determine its response. Data recorded during the response tests could be compared later with the model run data under similar conditions.

The tests were conducted during May 1991 on the concrete apron between E and F hangars at Naval Air Station Nowra.

2. TEST PROCEDURE

For the duration of the tests the instrumented aircraft was parked on a level concrete-surfaced apron area with its starboard wheel chocked. A mobile crane was positioned on the tarmac on the port side of the aircraft so that the hook on the extended boom overhung the desired lifting point (Fig. 1).

A load cell was inserted in the lifting cable between the crane hook and the quick-release hook to indicate the weight being supported by the crane. To raise the tail a sling was attached to the two fuselage tie-down rings behind the tail landing gear. A series of tail lifts was then carried out with the tail being raised to extend the tail oleo over the range of 168 to 532 millimeters (6.61 to 20.94 inches).

The port side main landing gear (MLG) was raised with the sling attached to the tie-down ring above the oleo near the top of the fuselage . The port side was then raised to extend the MLG oleo over the range of 154 to 388 millimeters (6.06 to 15.28 inches).

A total of sixteen releases was performed during the test program of which eight releases involved raising the tail and a further eight involved raising the port side landing gear. Eleven releases were with normal tyre and oleo pressures and five with reduced pressures in the tyres and oleos . The brakes were applied for nine of the releases while the other seven releases were performed with the brakes off.

The aircraft is certified for single engine landings so no need existed to run the engines, but to avoid the possibility of damage occurring to the gyros the aircraft was supplied with auxiliary power so that the gyros were functional during the tests. Electrical power to operate the ARL VADAR and transducers was derived from the 240 volt AC mains.

3. MAIN LANDING GEAR

3.1 Main Wheel Tyre

The deflections of both main wheel tyres were measured using Linear Variable Differential Transformers (LVDTs) (Fig. 2). The LVDTs had castors attached to extended cores and were spring biased to maintain ground contact. The castors provided protection to the transducers in the event the aircraft's port wheel rolled over the ground following the release from the crane.

The LVDT mounting plates were attached in place of tie-down rings to fittings at the outboard ends of the axles. The LVDTs were adjusted to be vertical while the MLG radius arms and oleo struts were at their static positions. Because only the port side MLG was extended by the crane the port side tyre LVDT position was adjusted so that the fully compressed position of its core spring coincided with the maximum distorted position the tyre was likely to adopt.

As the aircraft was raised and the MLG oleo extended the LVDT attached to the end of the axle traversed through an arc determined by the length of the MLG radius arm and the oleo extension limits. The LVDT core then extended downwards at an angle to the arc tangent introducing a maximum uncorrected error of 6% into the tyre measurement. An analysis of this error and the error correction required is provided in APPENDIX 1.

Because the core stroke of the LVDT assigned to measure the main wheel tyre deflections was limited to 100 mm, the tyre made ground contact slightly before the castor for those helicopter releases when the main wheel was raised clear of the ground. The initial tyre deflection (first few mm) was therefore not recorded but the full oleo travel was recorded.

3.2 Main Gear Shock Strut

The MLG oleo-pneumatic shock struts (oleos) had LVDT's clamped to their upper housings using two figure-of-eight arrangements of Jubilee type clips. The core rod ends were attached to right angle brackets installed on the strut's inflating valve stems at the base of the oleos (Fig. 3).

The LVDT's were mounted on both the port and starboard sides such that the core movements were parallel to the line of motion of the oleos and so provided outputs that were direct measurements of the oleo movements.

4. TAIL LANDING GEAR

4.1 Tail Wheel Tyre

The LVDT for measuring the dual type tail wheel tyre deflections was mounted to a plate that was attached to the axle on the port side (Fig. 4a). A tubular spigot on the back of the plate fitted into the towing bar recess in the end of the axle and a bolt that tightened into a conical nut spread the spigot to hold it in place.

The LVDT layout arrangement and the plate dimensions were chosen to keep the assembly within the confines of the area of the tail wheel tyre thus ensuring that there would be adequate clearance from the fuselage when the tail oleo was fully compressed.

The horizontally mounted LVDT was operated by a vertical push rod that protruded below the tyre and contacted the ground ahead of the tyre. A right angled arm converted the push rod vertical motion into the horizontal movement to operate the LVDT core.

The tail wheel and its axle are coupled and rotate together as one unit. The tail oleo has a five degree angular incline to the vertical so that the lower end and the tail wheel are positioned more rearwards than the upper end. As the oleo extended when the aircraft was raised, and while the tyre still remained in ground contact, the tailwheel with the LVDT plate attached was rotated rearwards This resulted in a 3% maximum uncorrected error in the measurement of tyre diameter. An analysis of this error and the error correction required is provided in APPENDIX 2. The analysis assumes that the wheel rotation ceased when the tyre left ground contact.

4.2 Tail Gear Shock Strut

The under fuselage hatch cover was removed from a compartment located forward of the tail wheel, to provide access to a bulkhead for attachment of a long stroke LVDT. An operating arm was clamped to the tail wheel jacking block and protruded forward to operate the LVDT core (Fig. 4b). The LVDT was mounted on the compartment bulkhead with fabricated brackets that were secured using existing screw holes. The core was then connected to the arm so that the core moved parallel to the line of the oleo movement to provide an output voltage that was a direct measurement of the oleo displacement.

5. FUSELAGE MOTION

A motion platform installed in the fuselage allowed data to be obtained on the fuselage motion occurring during the tests. The platform contained accelerometers, to measure the longitudinal, lateral, and vertical fuselage axial accelerations, and rate gyroscopes to measure the rates of pitch, roll, and yaw of the fuselage about these axes. A vertical displacement gyroscope provided the data on the roll and pitch angles of the fuselage.

6. VADAR

Data from all channels were recorded on an ARL developed Versatile Airborne Data Acquisition and Replay (VADAR) system (Reference 2). VADAR consists of a portable AT type PC fitted with additional cards, signal conditioning circuits and power supplies.

The signals from the fifteen selected channels were amplified, passed through low-pass filters then sampled 50 times/sec/channel and digitised by an Analog Devices RTI-815 analogue to digital card inserted in the COMPAQ PC. The 12 bit data words were stored in volatile memory until the end of the run and automatically copied with unique file names to the PC hard disk. Subsequently the data were transferred to floppy disks for laboratory processing.

Because the tests were ground based only, the DAS and the associated mains operated power supply used were firmly secured to the aircraft floor with webbing straps, at a known location near the starboard side door.

The transducer output signal voltages were connected to differential inputs of the VADAR signal conditioning module with shielded cables. Selectable links on boards in the signal conditioning module provided control over offsets, gain and filter cut-off frequencies for each of the analogue signals. A tabulation of the DAS channel allocation, gain and cut-off frequency link settings is provided in APPENDIX 3.

7. CALIBRATION

A calibration of most data channels followed the installation of the recording system in the aircraft. The calibration records obtained are tabulated in TABLES 1-4 of APPENDIX 4.

The LVDT channels were statically calibrated by lifting the aircraft to extend the landing gear oleos by measurable steps. Recordings were then made at each position of the oleos using the DAS while the actual oleo and tyre displacements were measured.

Accelerometer channels were calibrated by positioning each of the accelerometers so that their pendulous mass was effectively subjected to $\pm 1g$ from the earth's gravitational field while recordings were made with the DAS.

Because of the difficulty of applying controlled inputs to rate gyroscopes as part of the installation, the gyro channels were calibrated in the laboratory for the angular rates it was anticipated they would encounter in service. The same electrical connectors and cables used for the calibration were subsequently installed in the aircraft.

8. VIDEO RECORD

Each crane release of the aircraft was video recorded to enable a laboratory study of the tyre deformation to be undertaken at a later stage. Two small Charge Coupled Device

(CCD) cameras were positioned to view the selected tyre as it contacted the ground. One camera viewed the side of the tyre while the other camera simultaneously viewed the tyre end on.

The recordings made will be analysed using image processing equipment which should then supplement the transducer data obtained.

9. ULTRASONIC TRANSDUCER

An ultrasonic position sensing transducer (UST) was installed on the fuselage near the starboard main oleo to provide additional fuselage to ground distance data for comparison with the LVDT data.

On this occasion the UST method gave good agreement with the LVDT method. However, when the UST was used previously to measure the fuselage to ground distance during a flight trial, an apparant inconsistancy was detected with the distance measurement

A problem identified with the UST recovery time has been minimised and is detailed in Reference 3.

10. CONCLUSION

The instrumentation system was installed and a series of ground tests performed successfully. The acquired data should provide both static and dynamic parameter values for a computer simulation model. A summary of the test conditions is tabulated in APPENDIX 5 and data plots showing the response of various components for two sets of test conditions are shown in APPENDIX 6.

Much of the equipment used may need to be reinstalled on an aircraft if the model is to be extended to investigate problems such as the stability and tie-down forces on the aircraft when hangared aboard a FFG class of ship at sea. This memorandum provides a detailed record of the instrumentation and test procedures used and will minimise duplication of the effort in future trials.

ACKNOWLEDGMENT

The work was initiated and devised by Dr. J. Blackwell of Rotary Wing Group ARL. The aircraft was made available by the RAN and the authors appreciated the co-operation and technical assistance provided by members of Aircraft Maintenance and Flight Trial Unit at Naval Air Station, Nowra.

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APPENDIX 1

Error analysis of main tyre LVDT measurement

Referring to the diagram which is based on Sikorsky landing gear assembly drawing No 70000-32100 for the -043 oleo, note the radius arm moves through an angle of 19.8 deg. as the oleo extends from the static to the extended position. This means the LVDT becomes inclined at 19.8 deg. to the vertical when the oleo is fully extended and so the transducer measurement over indicates the change in tyre radius.

At any other position of the oleo the angle of the radius arm from the static position is found from

$$\Theta = \Theta_t - 18.2$$

Where:

Θ_t is the angle subtended by the radius arm from the horizontal
18.2° is the radius arm static position angle from the horizontal.

$$\Theta_t = \arcsin (9.95+E)/R$$

Where:

E is the actual oleo ext.
R is the rad arm length (= 31.84in.)
9.95 = WL201.75 - WL191.80

The corrected tyre distance at the maximum extended oleo position is a component of the indicated distance found from

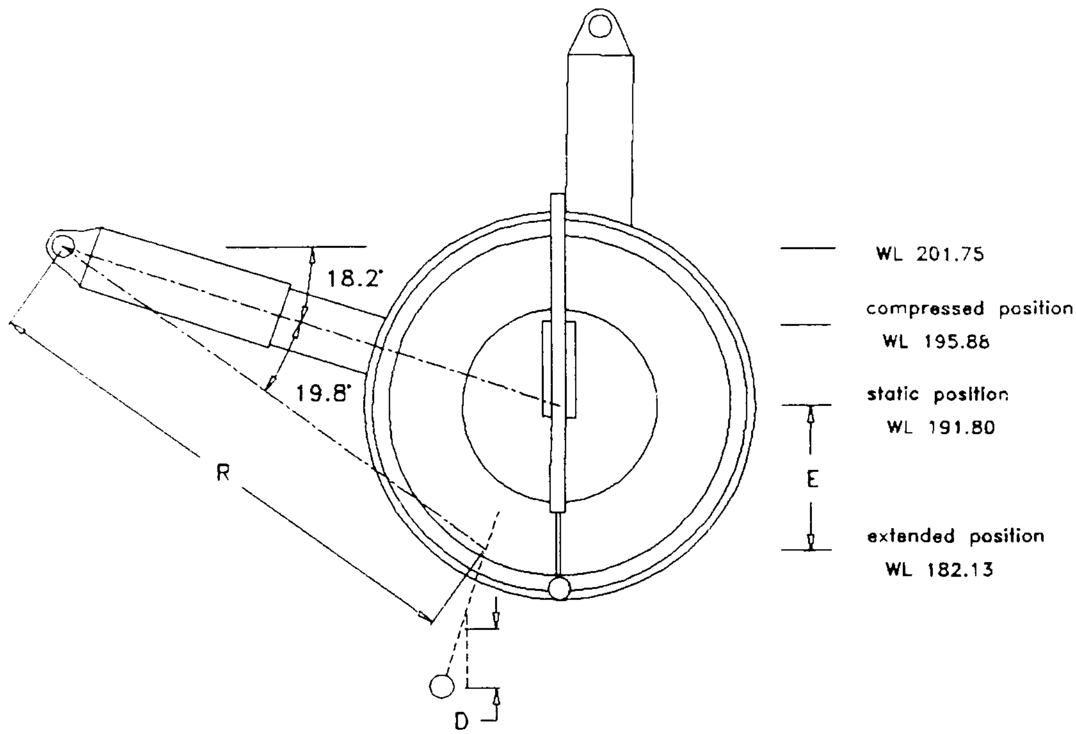
$$D = D' \cos\Theta$$

Where:

D' is the indicated tyre dist.

$$= D' \cos 19.8$$
$$= 0.94\ D'$$

ie D is about 6% less than D' indicated by the tyre LVDT



MLG Tyre Transducer Arrangement

APPENDIX 2

Error analysis of tail wheel tyre LVDT measurement

Referring to the diagram of the tail landing gear which is based on Sikorsky Drawing No 70250-93800 note that as the oleo extends the tyre rolls along the ground a distance given by:

$$S = E \sin\phi$$

Where:

E is the oleo extension from static pos
and ϕ is the oleo rake angle (= 5°)

$$S = 0.087\ E$$

The angular rotation of the wheel for this arc length of tyre rotation is

$$\Theta = S/r$$

Where:

r is the tyre rolling radius assumed constant at 6.9in.

$$= 0.087E/6.9$$

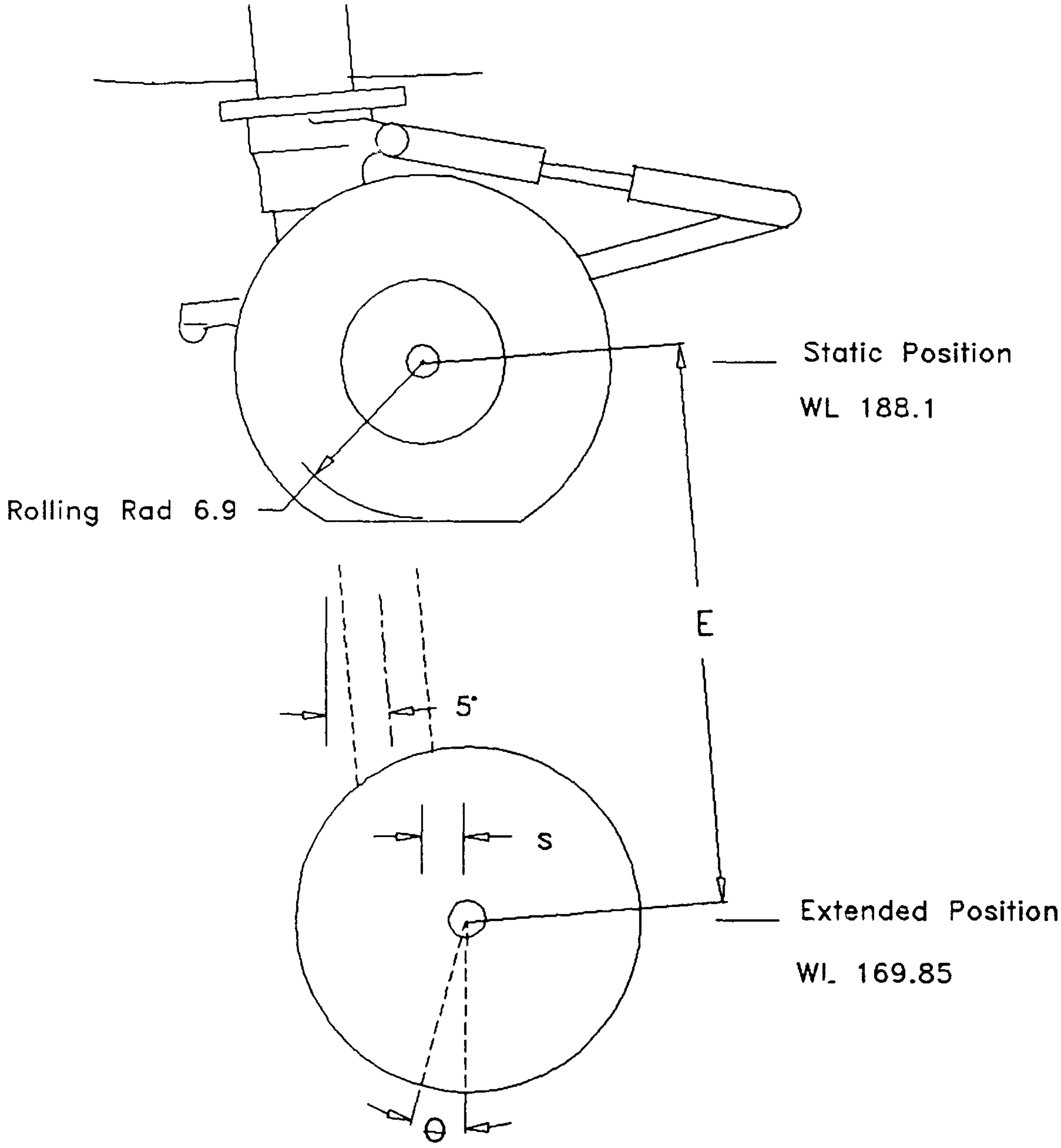
For maximum oleo extension E of 18.32in.

$$= 0.087 \times 18.32 \times 57.3/6.9$$
$$= 13.2°.$$

The corrected tyre distance D or vertical component of the LVDT measurement D' for this ground rotation of the tail wheel is

$$D = D'\cos\Theta$$
$$= D'\cos 13.2°$$
$$= 0.97\ D'$$

ie D is 3% less than D' indicated by the tyre LVDT



Tail Wheel Tyre Arrangement

APPENDIX 3

VADAR - ANALOGUE CHANNEL ALLOCATION TABLE

CHAN	SIGNAL	INPUT SENS	LINKS Gain	Freq(Hz)
A0 1	Tail oleo	13mv/mm	1SE	17
A0 2	Tail tyre	50mv/mm	2SE	17
A0 3	Roll att	210mv/deg	2SE	17
A0 4	Pitch att	212mv/deg	1SE	17
A0 5	Port oleo	8mv/mm	2SE	17
A0 6	Port tyre	32mv/mm	3SE	17
A0 7	Stb oleo	8mv/mm	2SE	17
A0 8	Stb tyre	48mv/mm	2SE	17
A0 9	Yaw rate	245mv/deg/sec	2SE	17
A010	Pitch rate	83mv/deg/sec	2SE	17
A011	Roll rate	83mv/deg/sec	2SE	17
A012	Long accln	0.47v/g	7SE	17
A013	Lat accln	0.44v/g	7SE	17
A014	Vert accln	0.44v/g	5SE	17
A017	Stb ultson	5.5mv/mm	1SE	17

TRANSDUCERS USED

FUNCTION	TRANSDUCER	RANGE useable
MLG oleo	Sangamo DC250	250mm
MLG tyre	Schaevitz 5000HR	50mm
Tail oleo	Trans Tek 0223	380mm
Tail tyre	HP 7DCT-3000	50mm
Stb f'lage	Honeywell 941	0.3-1.8M

LINK SETTING	CHANNEL GAIN
1SE	0.735
2SE	1.464
3SE	2.186
5SE	3.625
7SE	5.097

APPENDIX 4

PORT SIDE LANDING GEAR CHANNELS (Static Calibration)

LVDT core ext. (cms.)	OLEO strut ext. (cms.)	DAS output (volts)
42.20	41.70	-1.86
34.25	33.70	-0.91
26.00	25.70	0.04
18.15	17.75	0.99
17.40	16.90	1.08

LVDT core ext. (cms.)	TYRE rim to ground (cms.)	DAS output (volts)
9.35	16.80	3.55
5.85	14.40	0.99
4.65	13.70	0.08
3.50	12.90	-0.75
3.70	13.00	-0.60

STARBOARD SIDE LANDING GEAR CHANNELS (Static Calibration)

LVDT core ext. (cms.)	OLEO strut ext. (cms.)	DAS output (volts)
41.60	41.75	-1.55
34.15	34.45	-0.65
25.90	26.00	0.30
18.30	18.30	1.19
14.60	14.75	1.66

LVDT core ext. (cms.)	TYRE rim to ground (cms.)	DAS output (volts)
9.95	16.70	3.74
6.90	14.45	1.62
5.90	13.90	0.97
5.30	13.30	0.53
4.40	12.45	-0.14

TABLE 1

TAIL LANDING GEAR CHANNELS (Static Calibration)

LVDT core ext. (mm)	OLEO ext. (mm)	DAS output (volts)
552.0	514.0	0.91
441.0	403.0	-0.15
339.0	299.0	-1.16
224.0	183.5	-2.27
120.5	77.0	-3.28

LVDT upper push rod length (mm)	TYRE sidewall comp. dist.(mm)	DAS output (volts)
1.5	4.7	3.27
15.0	18.7	2.87
19.0	24.3	2.55
25.0	30.2	2.13
41.5	45.2	0.84

Tyre sidewall compressed distance was found by measuring the axle to ground distance for an unloaded tyre and subtracting the axle to ground distance obtained during progressive static loading of the tyre.

STARBOARD ULTRASONIC CHANNEL

ULTRASONIC f'lage to ground dist (cms.)	DAS output (volts)
32.0	0.34
87.9	1.14
136.0	1.79
169.0	2.26

TABLE 2

VERTICAL GYRO CHANNELS (Calibrated using an Inclinometer)

PITCH angle (deg.)	DAS output (volts)
-20	-2.75
-15	-2.10
-10	-1.42
- 5	-0.69
0	0.03
5	0.90
10	1.65
15	2.35
20	3.07

ROLL angle (deg.)	DAS output (volts)
-15	-4.13
-10	-2.62
- 5	-1.15
0	0.40
5	1.94
10	3.39
12	4.00

RATE GYRO CHANNELS (From Rate Table Calibration)

PITCH rate amp i/p (volts)	DAS output (volts)
-2	-2.92
-1	-1.45
0	0
1	1.50
2	2.97

ROLL rate amp i/p (volts)	DAS output (volts)
-2	-2.93
-1	-1.46
0	0
1	1.48
2	2.94

YAW rate amp i/p (volts)	DAS output (volts)
-2	-2.94
-1	-1.46
0	0
1	1.45
2	2.91

TABLE 3

ACCELEROMETER CHANNELS (Static Positioning of Transducer)

LONG. accln. (g)	DAS output (volts)
1	2.48
0	0.07
-1	-2.35

LAT. accln. (g)	DAS output (volts)
1	2.35
0	0.07
-1	-2.22

VERT. accln. (g)	DAS output (volts)
1	1.84
0	0.22
-1	-1.41

TABLE 4

APPENDIX 5

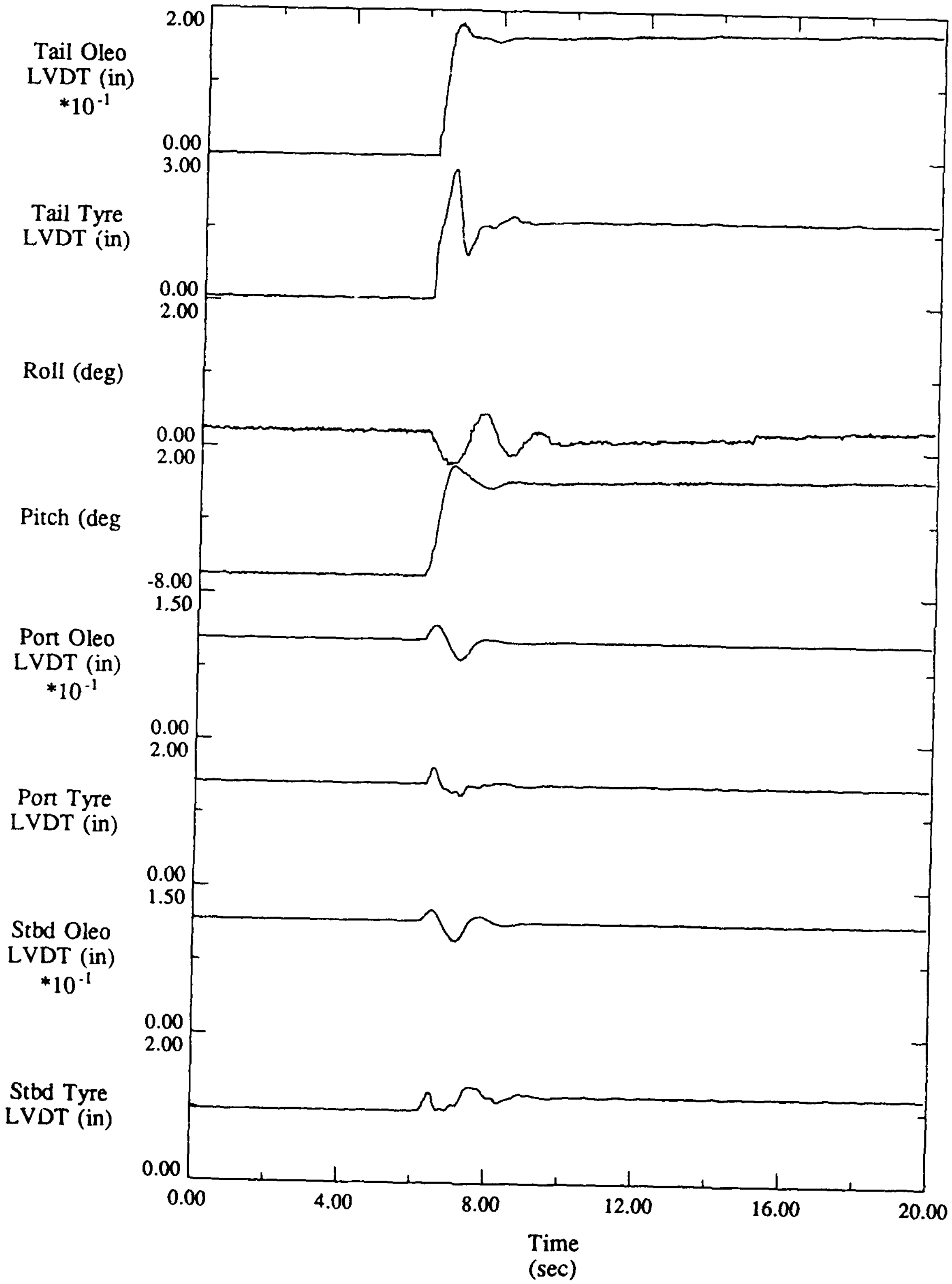
Dynamic Undercarriage Trial - Nowra - May 1991

Drop Number	File	Gear Raised	Gear Pressures	Brake Status	Distance Raised (in)*	Length of Run (s)	Time till Impact (s)
1	08051338	Tail	Normal	On	6.61	19.90	7.84
2	08051407	Tail	Normal	On	12.28	7.90	2.70
3	08051415	Tail	Normal	On	12.56	7.90	2.40
4	08051422	Tail	Normal	On	18.58	12.92	5.94
5	08051511	Tail	Normal	On	20.94	17.88	4.80
6	08051533	Port	Normal	On	6.06	13.94	4.34
7	08051542	Port	Normal	Off	6.38	14.88	5.25
8	08051548	Port	Normal	Off	10.08	12.92	3.04
9	08051604	Port	Normal	Off	15.28	11.90	4.40
10	08051609	Port	Normal	Off	13.94	13.94	4.94
11	09050939	Tail	Normal	On	20.94	19.90	6.26
12	09051139	Tail	Reduced	On	9.96	64.88	3.98
13	09051146	Tail	Reduced	On	16.93	43.88	3.90
14	09051203	Port	Reduced	Off	8.4†	85.90	7.64
15	09051208	Port	Reduced	Off	8.3†	23.06	5.48
16	09051212	Port	Reduced	Off	12.8†	49.92	4.92

* Along Line of Oleo being Raised

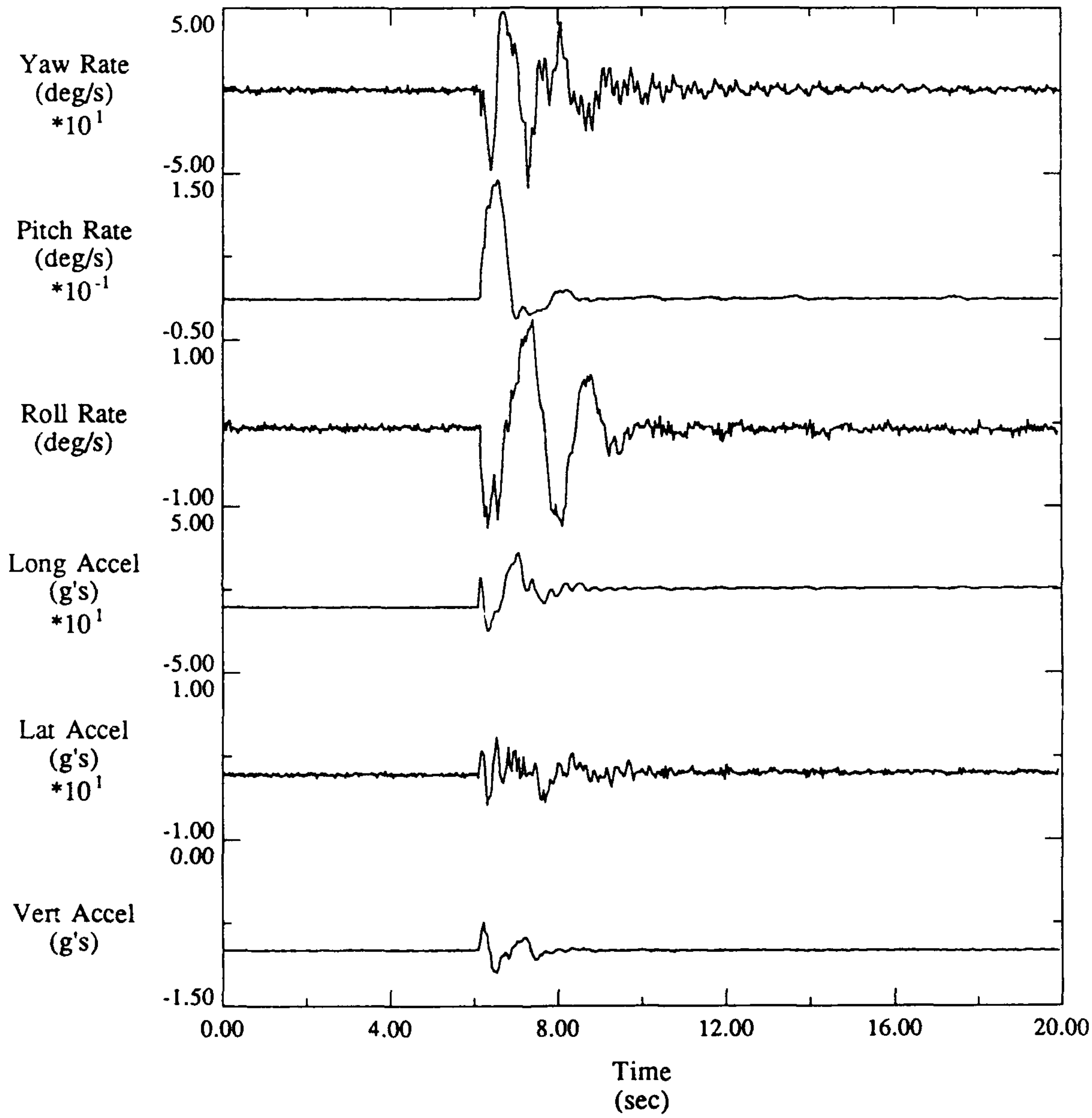
† Estimated

APPENDIX 6



09050939.DAT

RESPONSE OBTAINED FROM DROP NO 11



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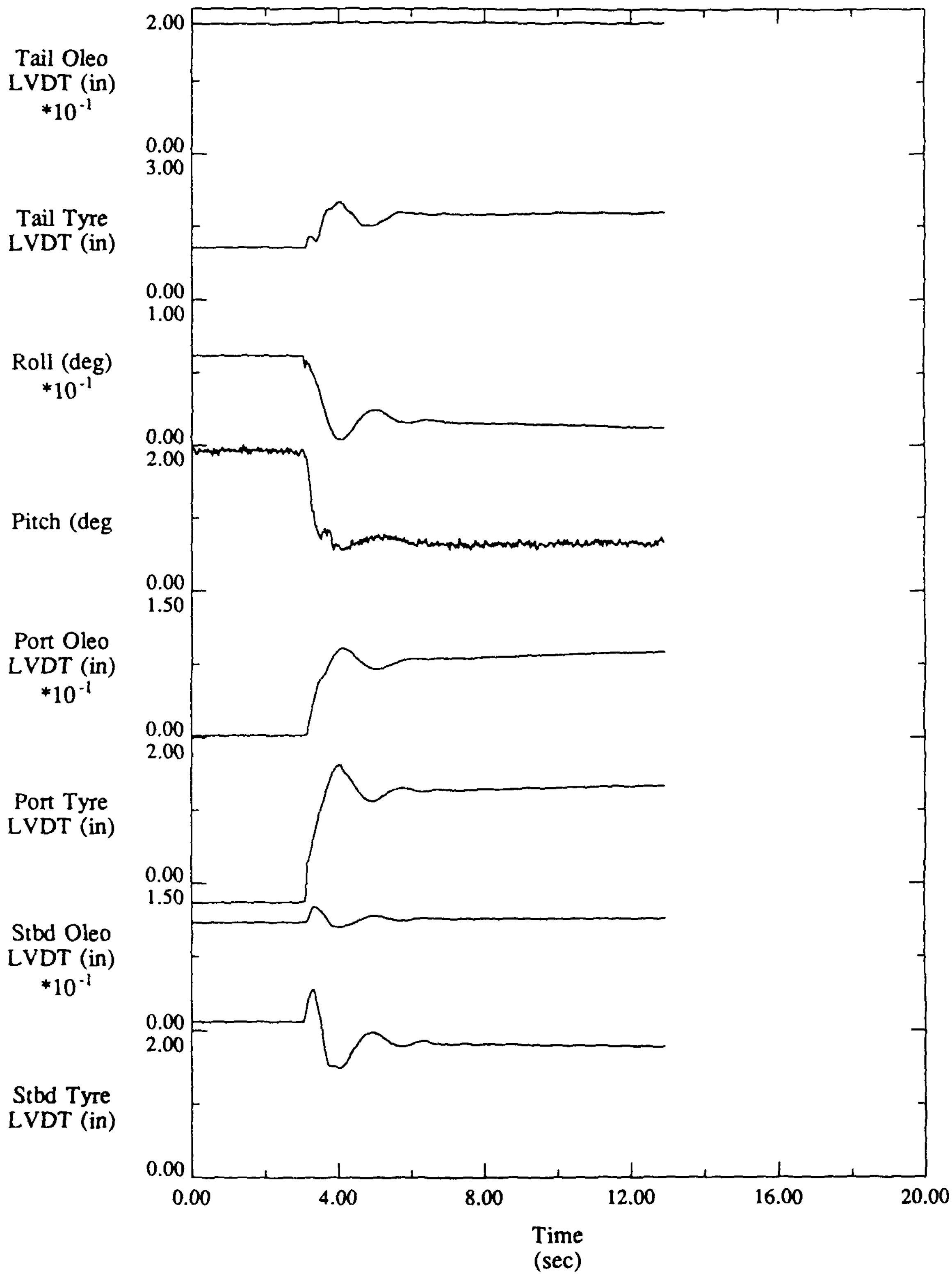
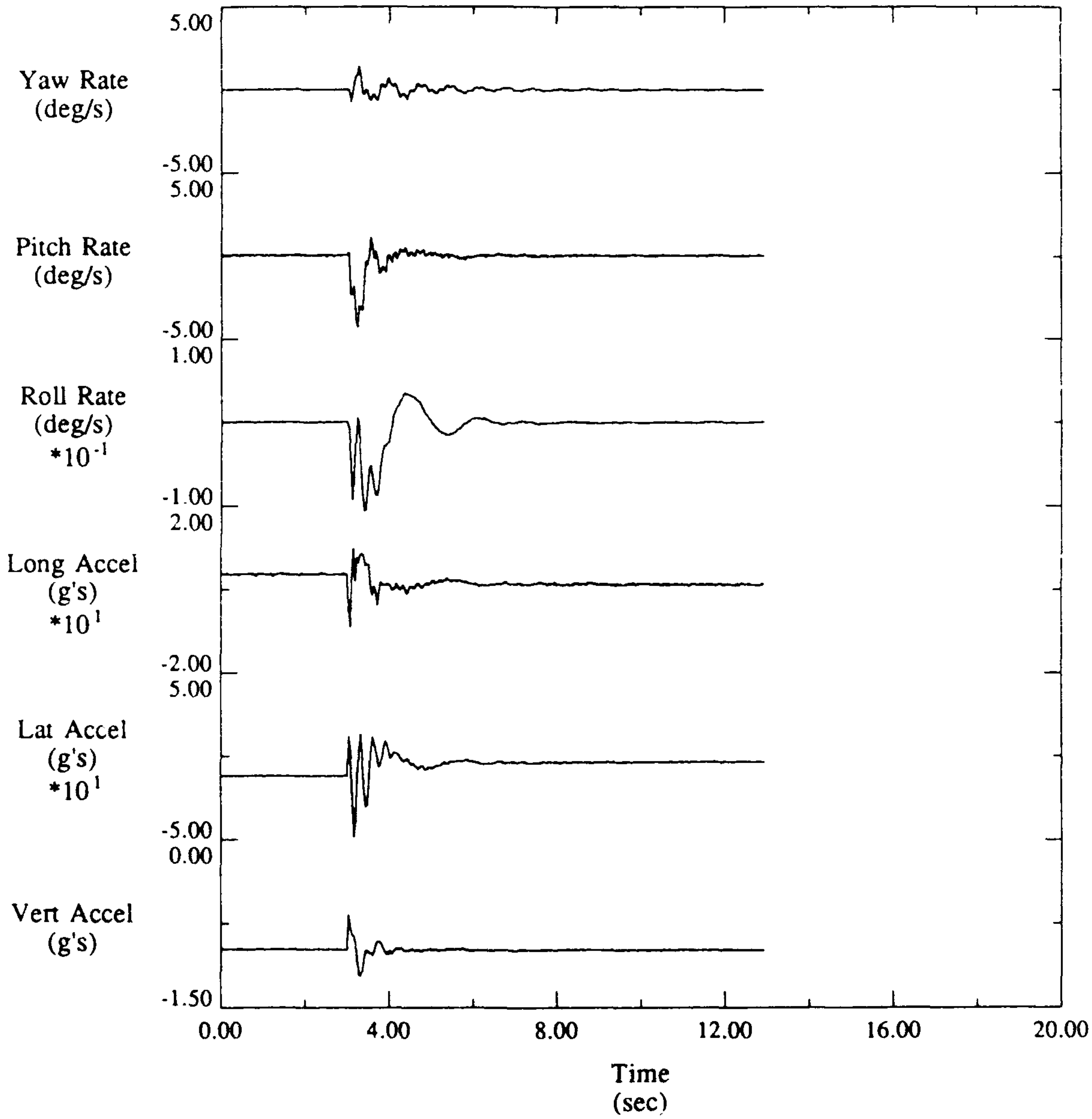


08051548.DAT

RESPONSE OBTAINED FROM DROP NO. 8.



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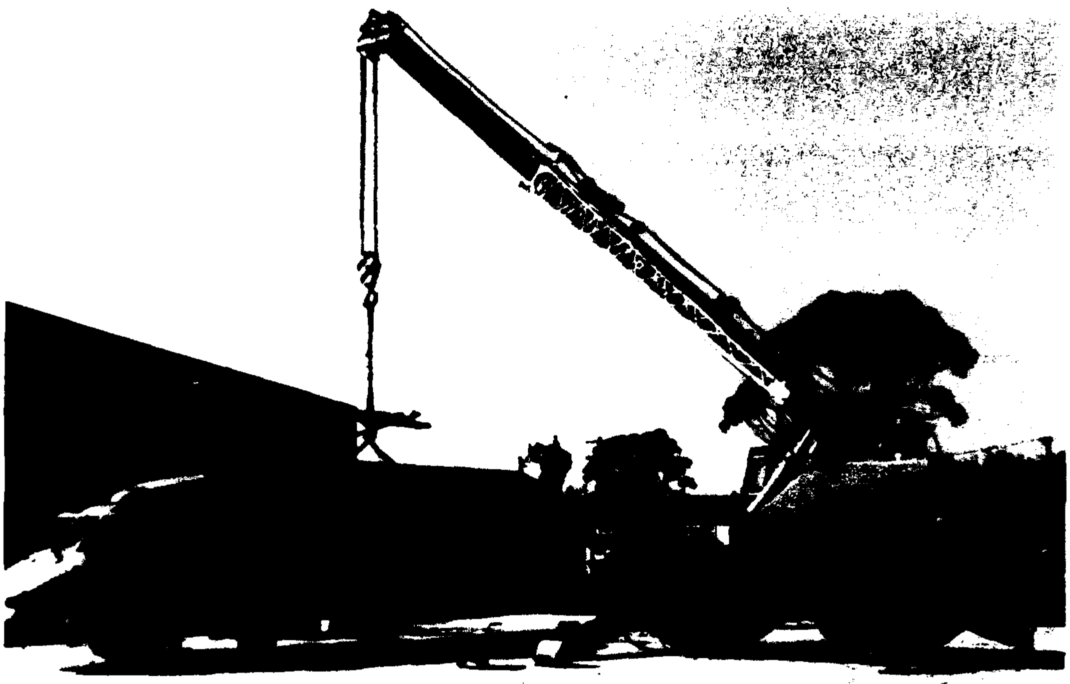

FIG. 1 CRANE POSITIONED TO LIFT HELICOPTER TAIL

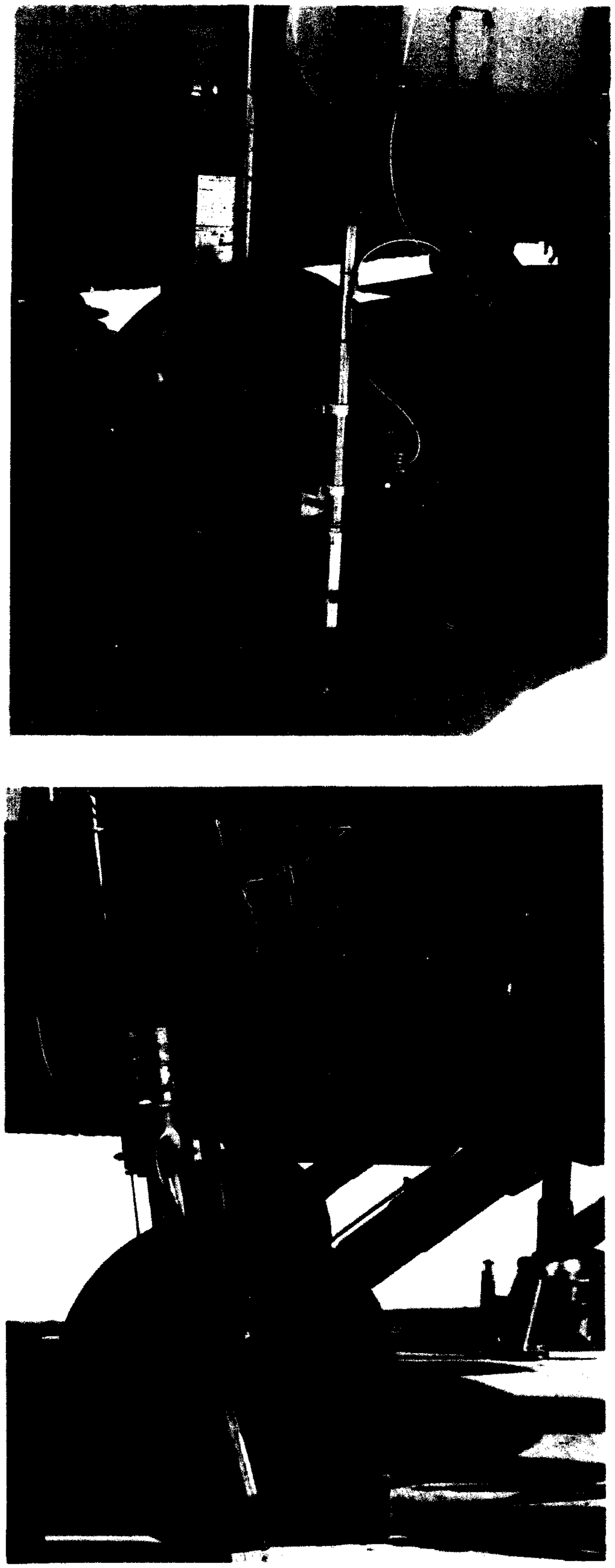

FIG. 2 TYRE L.V.D.T. PORT AND STARBOARD

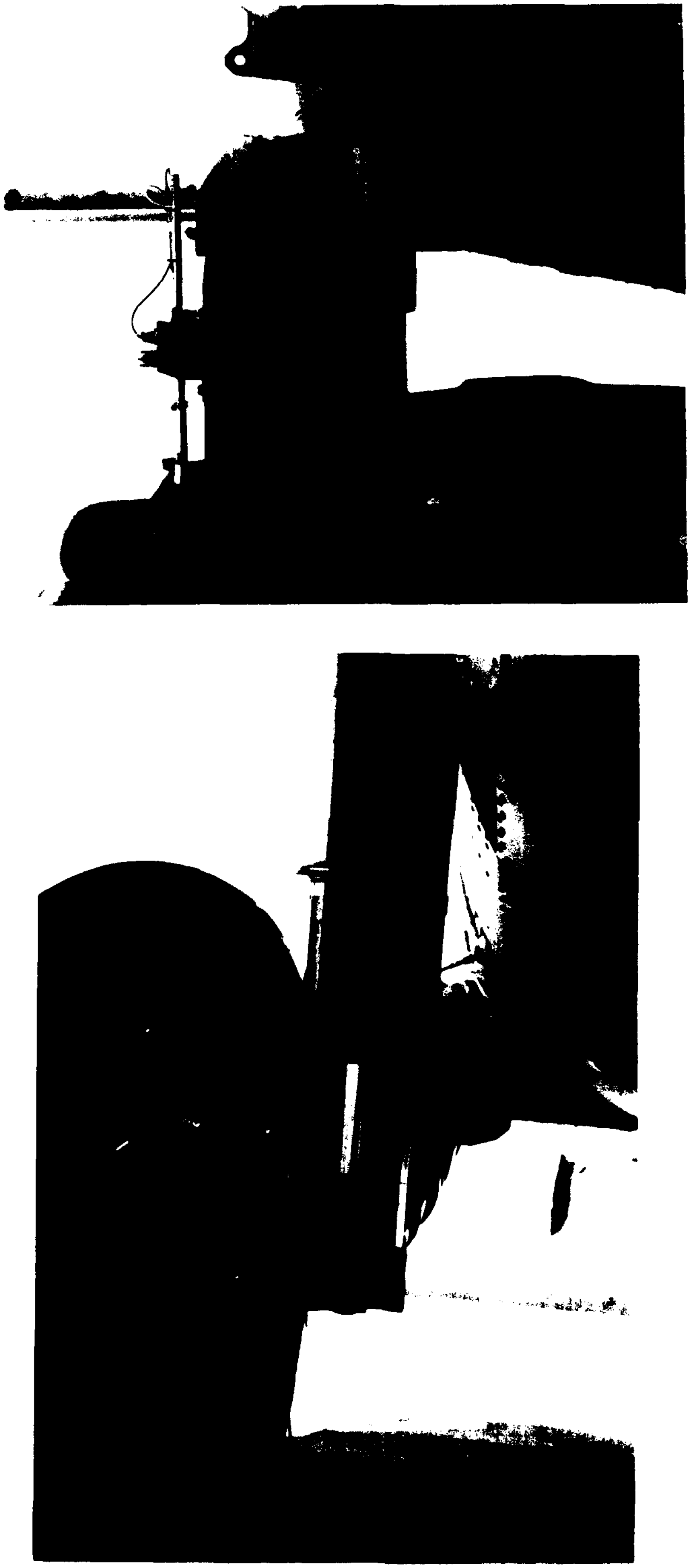

FIG. 3 L.V.D.T. MOUNTING PORT SIDE OLEO

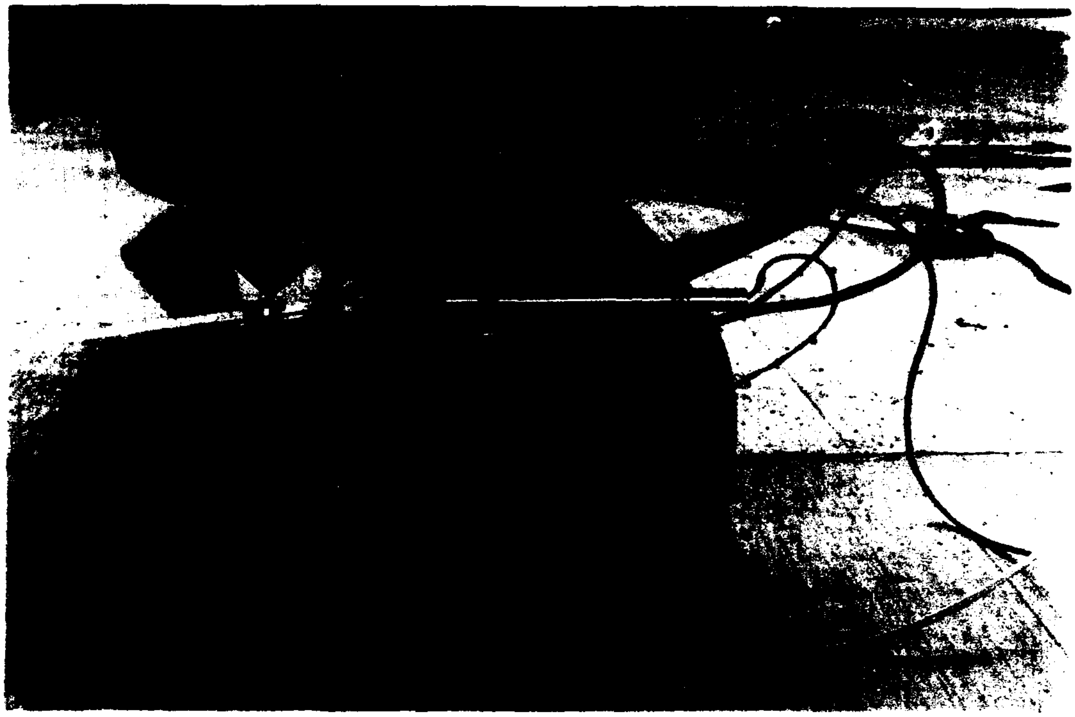

FIG. 4a TAIL WHEEL TYRE L.V.D.T.

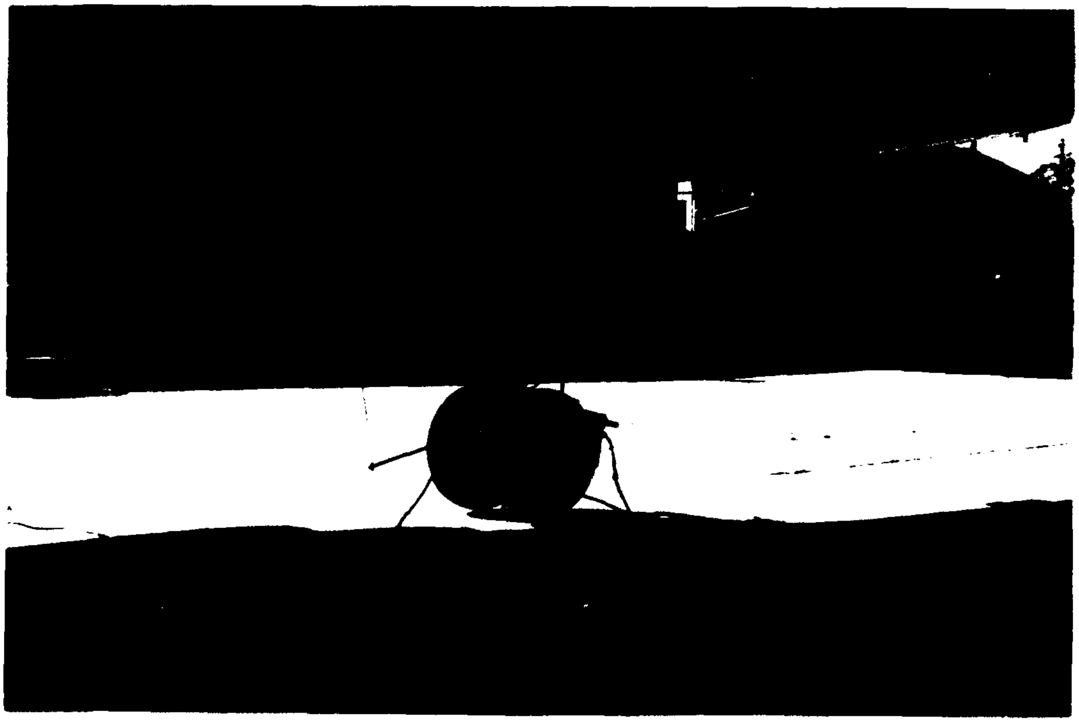

FIG. 4b TAIL OLEO L.V.D.T. OPERATING ARM

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